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PRELIMINARY EVALUATION OF COMMERCIAL ADDITIVES USING FOUR-BALL TRIBOTESTER MACHINE

Bukhari Manshoor[1], Mohd. Zaki Bahrom[1,2], Norfazillah Talib[1] and Zulkifli Mohamed[3]
[1]Faculty of Mechanical Engineering and Manufacturing Universiti Tun Hussein Onn, Batu Pahat, Johor, Malaysia
[2]Automotive Engineering Section, Universiti Kuala Lumpur Malaysia France Institute, Bandar BaruBangi, Selangor, Malaysia
[3]Sports Engineering and Artificial Intelligence Centre, College of Engineering Universiti Teknologi MARA Shah Alam, Selangor, Malaysia
E-Mail: zaki.bahrom@gmail.com

ABSTRACT

This study evaluates the kinematic viscosity, coefficient of friction, and wear scar diameter of the commercial additive (CAA) with engine oil. The base oil, synthetic engine oil (SEO) SAE 10W40, has blended physically with selected CAA in a volume ratio of 1:0.06. The results show that one of the blended SEO and CAA increases the kinematic viscosity value at temperatures of 40°C and 100°C. However, the value of the coefficient of friction and wear scar diameter blended between SEO and CAA is higher compared to pure synthetic engine oil. Based on the finding of this study, the role of additional commercial additives can be applied to improve several of the lubricant properties, such as viscosity. It has been demonstrated that synthetic engine oil is superior without additional commercial additives for automotive lubrication.

Keywords: four-ball tester, ASTM D4172, commercial additives, engine oil.

1. INTRODUCTION

Most drivers know vehicle maintenance is called routine maintenance, such as replacing the engine oil according to time and mileage (km), either every six months or every 5,000 to 10000 km, depending on the vehicle and operation. Since the early 2000s, an oil life monitor system has been used to notify the driver to change the engine oil. The oil monitor will become visible on a dash lamp when the time to change the engine oil is needed. The drivers must follow the vehicle manufacturer's oil change intervals [1-3].

The operation of the vehicle engine is a very complex case. Many variables determine the engine oil degradation where the engine oil degradation proceeds differently for each reason, and the final effect degradation is also different. A few leading causes of engine oil degradation mechanisms include oxidation and nitration, contamination of metal wear products and soot, and dissolved fuel. According to Ewa Rotek, these mechanism results from high temperature and high load of the oil film, fuel penetration into the oil pan due to short-distance driving with a cold engine, regeneration of clogged diesel particulate filter, and frequent start-stop operation of the engine [2,4,5].

According to the oil change interval, replacing engine oil is the most important to avoid the high maintenance cost (Hala Abbas Laz & Mohamed Gomma Elnur, 2016**).** Lubricant engineers and chemists formulate engine oil to lubricate and cool moving engine parts and decrease engine wear due to metal-to-metal contact [6-10]. A complicated additives package is added to improve engine oil requirements such as lubricity, chemical stability, and nontoxicity (MOHANNAD O. RAWASHDEH, 2020). When a lubricant's base oil does not provide all the properties that the application requires, additives are needed to improve the good properties of the base oil and minimize the poor quality. The combination of additives in engine oil is a well-balanced package to allow the lubricant to reach certain performance criteria in a finished fluid. For example, the Dispersant Inhibitor additive package containing mainly dispersants, detergents, oxidation inhibitors, anti-wear agents, and friction modifiers is used for engine oil (Debbie Sniderman, 2017).

There are currently more than 50 products (Corporation, 2013) of additional commercial additives on the market. The existing commercial additives may help give engine components extra protection for longer oil life, reduced oil consumption, increased oil pressure, and increased fuel economy (McNally, 2021) if the drivers extend the oil replacement schedule. For example, nanoparticle additives can enhance friction and wear resistance in lubricant properties [6, 7}. Mitan *et al.* (Mitan, Mohammad Saifulazwan Ramlan, Mohamad Zainul Hakim Nawawi, & Zackris Kindamas, 2018) have studied the effect of aftermarket oil additives, mixtures of two types of engine lubricants, mineral engine lubricant, and semi-synthetic engine lubricant on a small motorcycle engine. The results show that the aftermarket oil additives have some role in lubricant performance with some limitations. The viscosity of engine lubricant has increased, and water content is reduced. The viscosity is one of the most important properties of maintaining a lubricating film between moving parts. It must be great enough to maintain a lubricating film and capable of flowing around the engine components under all conditions (Mohd Kameil bin Abdul Hamid, & Mohamad Shahidan bin Daud,, 2015). The author concluded that aftermarket oil additives could be utilized to enhance the lubricant performance and for maintenance purposes in motorcycle engines.

According to Andrzej (Mlynarczak, 2013), the result assessment of the aftermarket additives that have been done by scientific research does not show unequivocally. However, the function of aftermarket oil additives is essential in lubricant performance (Mitan,

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Mohammad Saifulazwan Ramlan, Mohamad Zainul Hakim Nawawi, & Zackris Kindamas, 2018). Commercial additives such as anti-wear (AW) and antiseizure (EP) improve friction point elements' working conditions by increasing boundary layer stability. The new boundary layer created by these additives added to lubricant oil can carry a greater load and decrease friction resistance and wear. It will increase lubricant oil service life and decrease the device operating cost (Mlynarczak, 2013).

This preliminary study will evaluate the coefficient of friction (COF) and wear of commercial additives on synthetic lubricant's performance using a four-ball tribotester machine. The four-ball tester machine was used because it is available commercially and extensively used in the industry for wear testing (Richard S. Gates & Stephen M. Hsu, 1980). The experiment follows the ASTM D4172 with a constant load [18,19].

2. EXPERIMENTAL RESEARCH

2.1 Preparation of Testing Materials

This study uses one litre of synthetic engine oils (SEO - SAE 10W-40) as a base oil (Table-1) to blend with selected commercial additional additives (CAA). The three products of AOA available in the spare part shop are chosen. The selected AOA is suitable for all engines (gasoline and diesel) and unknown types of additives. Each of the AOA was mixed according to manufacturer recommendations. The samples were labelled as per Table-2.

Table-1. The physical properties of engine oils.

SAE Grade	10W40
Viscosity @ 100 °C, cSt	13.0
Viscosity @40 °C, cSt	83.5
Viscosity index	155
Density, g/ml@15.6°C	0.86
Flash Point, °C	212
Pour Point, °C	45

Table-2. List of lubricants and additive blend.

Sample codes	Volume ratio lubricants and AEOA (litre)
Sample 1 (SEO)	1 : 0
Sample 2 (SEO + CAA 1)	1: 0.06
Sample 3 (SEO + CAA 2)	1: 0.06
Sample 4 (SEO + CAA 3)	1: 0.06

2.2 Viscosity Measurement

Viscosity is the most important characteristic of lubricant. There are two ways to measure viscosity: kinematic or dynamic (absolute) viscosity. The measurement is from flow times (s) and the viscometer constant (mm2/s2 or cSt) for determining kinematic values. The average kinematic viscosity values are used to report the kinematic viscosity result. Equation (1) shows the determination of kinematic viscosity (ASTM D445-17a. Standard Test Method for Kinematic Visocsity of Transparent and Opaque Liquids (and Calculation of Dynamic Viscosity), 2017)(ASTM D445-17a), and Equation (2) shows the dynamic viscosity related to kinematic viscosity (Farhanah & Bahak, 2015):

$$v_{1,2} = C \times t_{1,2} \tag{1}$$

where $v_{1,2}$is determined by kinematic viscosity values for v_1 and v_2 (mm^2/s), C is the calibration constant of viscometer (mm^2/s^2) and$t_{1,2}$ is flow times for $t_1$and t_2 (s).

$$\eta = \upsilon \times \rho \times 10^3 \tag{2}$$

Where $\eta$is dynamic viscosity (mPa.s), ν is the kinematic viscosity (mm^2/s), and $\rho$is the density (kg/m^3) at the same temperature of the kinematic viscosity.

In this experiment, the heated viscometer was used to measure the kinematic viscosity of the lubricants according to ASTM D445. The instrument measured viscosity by timing a metal ball's fall through the inner tube line, and the ball moved under gravity from side to side. The measurements are taken in both directions, and the instrument is tilted when the temperature is stable. The viscosity reading is taken at two temperatures, 40°C, and 100°C. The 100ml of lubricant oil is repeated three times for average reading. The instrument is cleaned with solvent (hexane) before the samples are tested.

2.3 Four-Ball Testers

Four ball tribotester machine (Figure-1) was used in this experiment to evaluate the anti-wear properties of the lubricant in sliding contact. The tests were carried out using a constant load of 40kg (392 N) at 1200 rpm by following American Standard Testing Material ASTM D4172 (ASTM D4172-94 Standard Test Method for Wear Preventive Characteristics of Lubricant Fluid (Four-Ball Method), 1999). Each sample was tested for 60 minutes at a temperature of 75°C. The test ball used in this test is chrome alloy steel with a 12.7mm diameter and was made from AISI standard steel No. E-52100, grade 25 extra polished (EP), has a Rockwell C hardness of 64 to 66. The oil cup and test balls were cleaned using hydrocarbon solvent (hexane) and carefully dried before conducting the test. The new test balls were used for each test. Figure-2 shows a four-ball tribotester where one test ball (top) is rotated against three stationary (lower) test balls firmly claimed together and immersed in the engine lubricant sample [3,14].

The value of the friction coefficient was determined to evaluate the lubricant performance and measured based on the average frictional force. A four-ball tester automatically generates the data based on the coefficient of friction Equation (2), where T is the coefficient torque (kg. mm), W is the force applied (kg), and r is the length between the centre of the contact

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surface on the lower test balls to the rotation axis. [18, 21, 22].

$$\text{COF} = \frac{T\sqrt{6}}{3Wr} \quad \text{or} \quad \text{COF} = 0.22248\frac{T}{W} \tag{3}$$

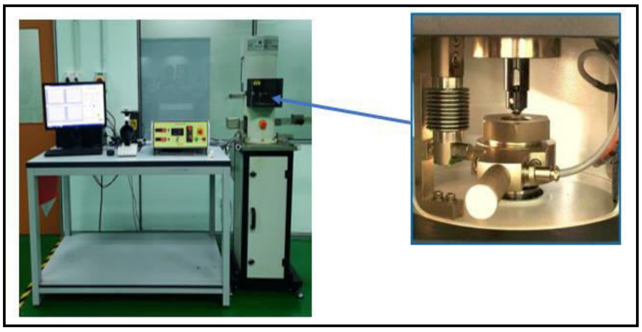

Figure-1. The view of Koehler K93190-M Four-ball Tribotester machine.

3. RESULTS AND DISCUSSIONS

3.1 Kinematic Viscosity Test

The kinematic viscosity values of all samples are shown in Figure-3. The viscosity has an inverse relationship with the temperature, where the viscosity decreases while the temperature increases [6, 12]. The viscosity of Sample 4 at 40°C is the lowest compared to Sample 1, Sample 2, and Sample 3, while Sample 3 is the highest. At a temperature of 100°C, the viscosity of Sample 3 is the highest among the other three samples. It shows that the temperature influences the viscosity of the lubricant. The thinner oil is more easily moved compared to the thicker oil. The increase in temperature will increase the fluidity and dilution of the lubricant (Farhanah & Bahak, 2015). Sample 3 shows the best lubricity performance, followed by Sample 1, Sample 2, and Sample 4. Normally, the higher viscosity has high anti-friction and anti-wear ability (Farhanah & Bahak, 2015).

3.2 Friction Torque

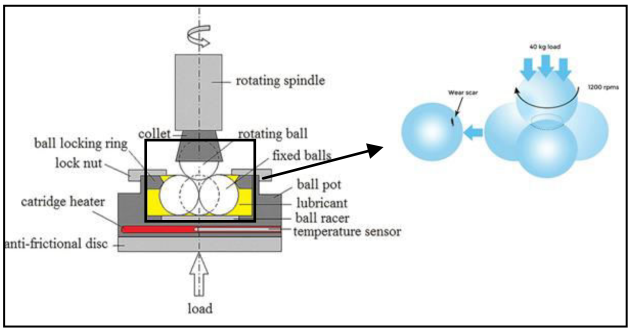

Figure-2. The top test ball is rotated against on top of the three lower test balls to measure the scar diameter.

A 40-kg load cell was used to measure the frictional torque. Figure-4 illustrates the graphs comparing the friction torque of fresh synthetic oil and the blend of synthetic oil with commercial additives. As illustrated in the figure, it can observe that at the initial time of the test, all samples graph increased with time before entering the steady state. After the test ran for around 4 minutes (260s), Samples 1 and 3 became constant. This represents that the material's surface has worn enough to adjust, and the lubricant could support the given load (Tiong Chiong Ing*, S., & A.K.).However, Sample 2 showed a sudden increase of friction torque after the test ran around 13 minutes (800s) until the end of the test, which indicated that the lubricant film formed had led to failure (Tiong Chiong Ing*, S., & A.K.).Sample 4showeda decrease in friction torque after the test ran around 12 minutes (750s) and became constant after the test ran around 42 minutes (2550s). Sample 1 showed a lower friction torque, and Sample 2 showed the highest friction torque compared to other samples of lubricant oil.

3.3 Friction Coefficient

Figure-5 illustrates the mean friction coefficient for the all-sample lubricants. As shown in Figure 5, Sample 2, Sample 3, and Sample 4 increased the coefficient of friction. Sample 1 has a lower friction coefficient than the oils containing additional additives. While for Sample 2 and Sample 4, the highest mean value of the friction coefficient is 0.13. The presence of additional additives in lubricant in Sample 2, Sample 3, and Sample 3 does not serve as a friction modifier.

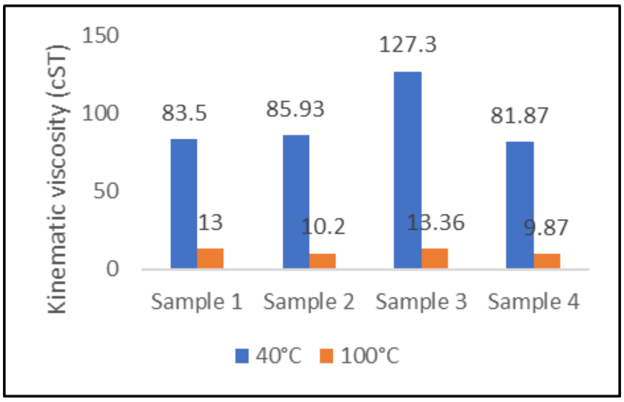

Figure-3. Result of kinematic viscosity.

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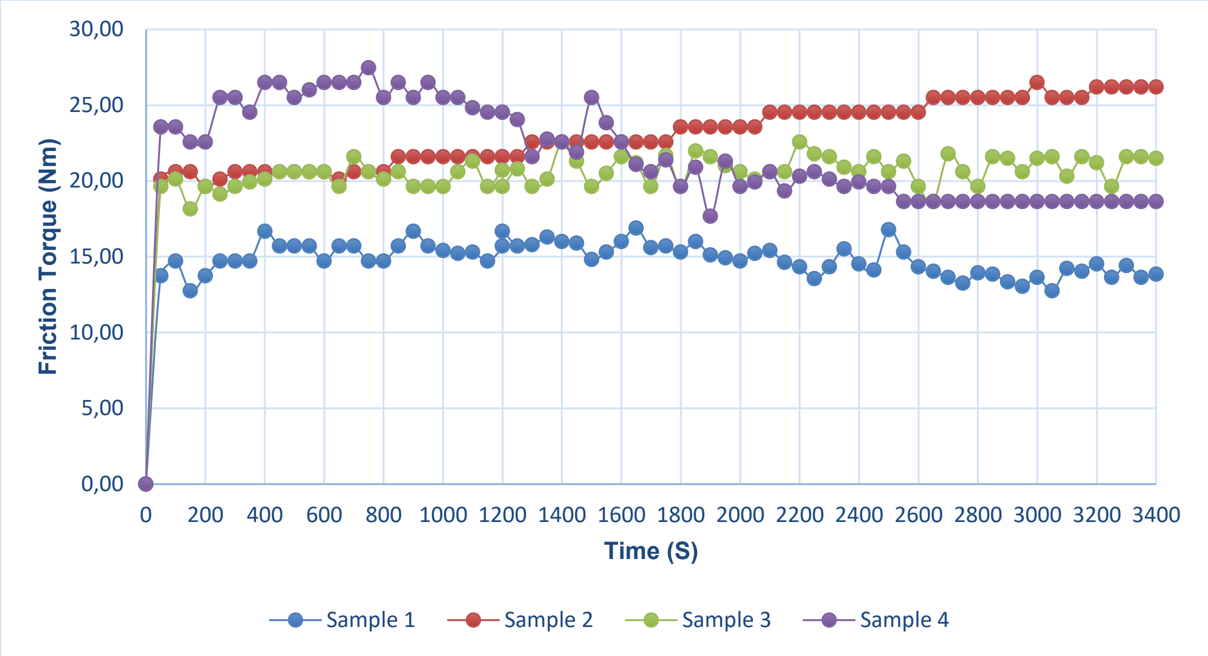

Figure-4. Friction torque for all samples lubricating oils.

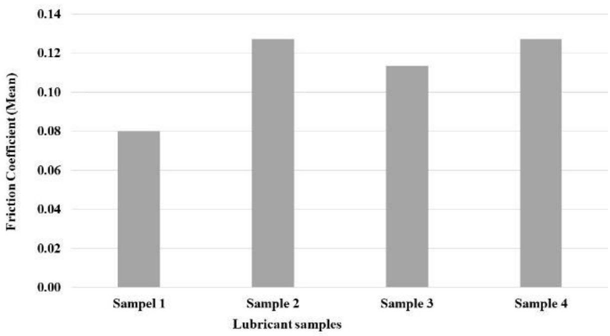

Figure-5. The friction coefficient of lubricant samples.

3.4 Wear Scar Diameter

Table-3 shows that the value wears scar diameter of Sample 2, Sample 3, and Sample 4 is increased compared to Sample 1. The wear scar diameter increases because the additive type does not act as the anti-wear agent to reduce friction and wear and prevent scoring and seizure. The other reason might be that the additives do not act as anti-oxidant agents whereas anti-oxidant additives will improve a surface film to reduce metal-to-metal contact. Therefore, the wear can be reduced (Farhanah & Bahak, 2015). Based on the viscosity result in Figure-4, the commercial additive blended with synthetic engine oil for Sample 3 is a viscosity improver. The viscosity improver can reduce the rate of viscosity change with the temperature. The additional additive used for Sample 2 and Sample 4 might keep surfaces free from deposits and neutralize the corrosive acids (detergent additive) or keep insoluble soot dispersed in the lubricant (dispersant additive).

Table-3. Results of wear test at speed 1200 rpm.

Speed (rpm): 1200	
Sample code	**Wear scar diameter (mm)**
Sample 1	0.200
Sample 2	0.540
Sample 3	0.324
Sample 4	0.794

4. CONCLUSIONS

The results of this study have been discussed in terms of kinematic viscosity, coefficient of friction, and wear scar diameter. The following shows the conclusion drawn based on the finding of the study:

a) It found the significant role of commercial additives blended with synthetic engine oil. The kinematic viscosity of Sample 3 is increased compared to other samples.
b) The additional additive type used in this study is not an acting anti-wear agent, friction modifier, or anti-oxidant. The value of the friction coefficient for Sample 2, Sample 3, and Sample 4 is higher than Sample 1 (pure synthetic engine oil). The additional additives used in this study were unable to improve tribological performances. The pure synthetic engine oil (Sample 1) without additional additives showed stable performance on friction coefficient and wear scar compared to other samples.
c) It has been demonstrated that synthetic engine oil is superior without commercial additives for automotive lubrication.

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